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Optimal Unit Commitment Based on Economic Dispatch Using Improved Particle Swarm Optimization Technique

Neha Thakur[1], L. S. Titare[2]

[1,2] Deptt. of Electrical Engineering, JEC, Jabalpur (M.P.), India

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***Abstract*: In this paper, an algorithm to solve the optimal unit commitment problem under deregulated environment has been proposed using Particle Swarm Optimization (PSO) intelligent technique accounting economic dispatch constraints. In the present electric power market, where renewable energy power plants have been included in the system, there is a lot of unpredictability in the demand and generation. This paper presents an improved particle swarm optimization algorithm (IPSO) for power system unit commitment with the consideration of various constraints. IPSO is an extension of the standard particle swarm optimization algorithm (PSO) which uses more particles information to control the mutation operation, and is similar to the social society in that a group of leaders could make better decisions. The program was developed in MATLAB and the proposed method implemented on IEEE 14 bus test system.**

***Keywords*: Unit Commitment, Particle Swarm Optimisation. Best individual particle, Best group particle, Voltage Security.**

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1. INTRODUCTION

Over the years, power systems had seen an immense shift from isolated systems to huge interconnected systems. These interconnected power systems are more reliable and at the same time have brought up many challenges in the operation from economics and system security perspective. Power systems can be divided into three main sub-systems called the Generation, Transmission and the Distribution systems apart from the power consumption at the end. The behaviour of all sub-systems is interdependent. Each of the sub-systems has its own behavioural attributes and constraints which govern overall system operation. Power systems have expanded the reach over a large geography for years to supply and cater to the ever increasing load demand. With this vast spread due to continuously growing power requirements, every utility in the world is facing a problem in reliable operation of system.

The need to supply of electricity to consumers with utmost importance towards reliability inclines utilities to plan at every level. In addition to reliability, an aspect that concerns utilities in planning is the economics involved in system operation. From the stage of power generation to the supply at consumer level, there exist many economic considerations. Thus, the planning steps followed should enable system reliable operation while optimizing the economics needed. The power system is subjected to a varying electric load demand with peaks and valleys at different times in a day completely based on human requirements. This urges the company to commit (turn ON) sufficient number of generating units to cater to this varying load at all times. The option of committing all of its units and keeping them online all the time to counter varying nature of load is economically detrimental [1] for the utilities.

A literature survey on unit commitment reveals that several methods have been developed to solve unit commitment [2, 3].They include dynamic programming method, It is a stochastic search method which searches for solution from one state to the other. The feasible states are then saved [4, 5]. Dynamic programming was the earliest optimization-based method to be applied to the UC problem. It is used extensively throughout the world. It has the advantage of being able to solve problems of a variety of sizes and to be easily modified to model characteristics of specific utilities. But the disadvantage of this method is curse of dimensionality. i.e., the computational effort increases exponentially as problem size increases and solution is infeasible and its suboptimal treatment of minimum up and downtime constraints and time-dependent start-up costs. Lagrange Relaxation method, In this method the constraints are relaxed using Lagrange multipliers. Unit commitment is written as a cost function involving a single unit and coupling constraints. Solution is obtained by adjoining coupling constraints and cost by Lagrange multipliers. Mixed Integer Linear Programming method, the method is widely used in the commitment of thermal units. It uses binary variables (0 or 1) to represent start up, shut down and on/off status of units. Even it guarantees optimal solution in finite number of steps; it fails when number of units increases because they require large memory space and suffer from great computational delay [6]. While considering the priority list method for the committing the units, replication time and memory are saved, and it can also be pertained in a genuine power system. In contrast, the priority list method has shortcomings that consequence into suboptimal solutions since it won't consider each and every one of the possible combinations of generation [7].

Section -2 presents problem formulation. Section-3 presents problem solution using DP algorithm. Section-4 gives implementation of developed algorithm on IEEE-14-bus system and section-5 gives conclusion.

2. FORMULATION OF UNIT COMMITMENT PROBLEM

Unit commitment can be defined as the selection of generators that must be operated to meet the forecasted load demand on the system over a period of time so that fuel cost is minimum [9,10]. The Unit Commitment Problem (UCP) is to determine a minimal cost turn-on and turn-off schedule of a set of electrical power generating units to meet a load demand [12] while satisfying a set of operational constraints. It is a well-known problem in power industry and helps in saving fuel cost if units are committed correctly so that fuel cost is saved.

A. Need for Unit Commitment:

(i) Enough units will be committed to supply the load.

(ii) To reduce loss or fuel cost.

(iii) By running the most economic unit load can be supplied by that unit operating closer to its better efficiency.

B. Factors Considered In Unit Commitment:

(i) For finding the nature of fluctuating load as well as to commit the units accordingly a graph is drawn between load demand and hours of use. This graph is known as load curve. In the solution load pattern for M period is formed using load curve.

(ii)The possible numbers of units are committed to meet the load.

(iii)The load dispatch is calculated for all feasible combinations and operating limits of the units have to be calculated. Unit Commitment is considered as a complex optimization problem where the aim is to minimize the objective function in the presence of heavy constraints The objective function is given by Minimize Total cost = Fuel cost + Start-up cost +Shut down cost

C. The input-output characteristic of a generating unit is obtained by combining directly the input-output characteristics of boiler and that of turbine-generator set [13]. A typical input-output characteristic also called fuel cost curve of a thermal generating unit is convex as shown in Fig. 1

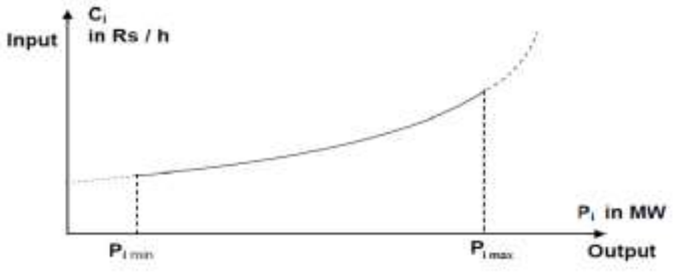

Figure 1. Input-output characteristics of thermal generator

This non liner curve can be approximated to a quadratic equation (1)

$$F(P_{gi}) = a_i Pg_i^2 + b_i Pg_i + C_i \qquad (1)$$

Where $F(P_{gi})$ represents the cost function, Pg_i is the power output anda_i, b_i, and C_i are the coefficients of input-output characteristic of *ith* unit. These cost coefficients are determined experimentally. The constant C_i is equivalent to the fuel consumption or cost incurred in operating the unit without power output. The slope of this input-output curve is called the incremental fuel cost of unit.

Start- up cost: When the unit is at rest, some energy is required to bring the unit online. It is maximum when the unit is at cold start (start- up cost when cooling). The unit is given sufficient energy input to keep it at operating temperature (start-up cost when banking). So it requires some energy input to keep it at operating temperature.

Shut down cost: It is the cost for shutting down the unit. Sometimes during the shutdown period boiler may be allowed to cool down naturally and thus no shut down cost will be incurred.

The two costs are as shown, and are compared while determining the UC schedule and a best approach among them is chosen [1].

Start-up cost for cold start: $STC = C_c(1 - \varepsilon^{-t/\alpha})F + C_f$ (2)

Start-up cost for hot start: $STC = C_t tF + C_f$ (3)

Where *STC* is the Start-up cost, C_c is the cold start cost in MBtu, *F* is the fuel cost, C_f is the fixed cost that includes crew expenses and maintenance expenses, C_t is cost in Mbtu/hour for maintaining the unit at operating temperature, α is the thermal time constant of the unit and *t* the time in hours the unit was allowed to cool. Shutdown cost is generally taken as a constant value.

D. constraints in unit commitment [11]:

1. Power balance: the total generated load and demand at corresponding hours must be equal

$$\sum_{i=1}^{ng} P_{gi} = P_d \qquad (4)$$

2. Minimum capacity committed: : It is the total power available from all units synchronised on the system minus present loads plus the losses. It is given by

$$\sum_{i=1}^{ng} P_{gimax} \geq P_d + P_{resv} \qquad (5)$$

3. Thermal constraints: The temperature and pressure of units increase gradually as the units are started. So they must be synchronised before bringing online.

4. Must run units: Some of the units must be given a must run status in order to provide voltage support for the network. For such units U_i=1.

5. Minimum up/down time:

$$T_i^{on} \geq T_i^{up} \qquad (6)$$

$$T_i^{off} \geq T_i^{down} \qquad (7)$$

6. Unit generation limits: The generated power of a unit should be within its minimum and maximum power limits.

$$P_{gimin} \leq P_{gi} \leq P_{gimax} \qquad (8)$$

7. Ramp rate constraints: The ramp rate constraint ensures that sufficient ramp rate capacity is committed to accommodate required generation changes. Any generation changes beyond the required changes are due strictly to economics of the committed generators.

$$P_{gi}^{t-1} \leq P_{gi}^{t} \leq P_{gi}^{t-1} + Rup_i \qquad (9)$$

8. Fuel constraints: The constraint means limited availability of fuel or burning of some amount of fuel.

Objective function: so the total cost can be represented by

$$total\ cost = \sum_{t=1}^{T}\sum_{i=1}^{NG}\left[U_i^t FP_{gi} + U_i^t(1-U_i^{t-1})STCi + U_i^{t-1}(1-U_i^t)STDi\right] \qquad (10)$$

3. PROBLEM SOLUTION USING PARTICLE SWARM OPTIMISATION METHOD

Since all the previous methods suffer from dimensionality and computation problems, a new method has been evolved in solving the unit commitment. It is known as Particle Swarm Optimisation method.[15].The method was developed by simulation of social model. The method is inspired from social behaviour such as "bird flocking‖" or "fish schooling"[8]. The method consists of a group of particles in a given dimension moving towards optimal solution. The particles move based on their previous best position, the position of neighbours and the best among all particles [14].Each particle move towards the optimal solution based on its previous best position given by Pbest, position of other particles and the best among all the other particles given by Gbest. The search is continued until a globally best solution is obtained or specific number of iteration is reached.

A. Algorithm of PSO:

It is known that a particle in the swarm flies through hyperspace and alters its position over the time iteratively, according to its own experience and that of its neighbours. Velocity is the factor responsible for this and which reflects the social interaction. If *xj* represents particle *x* in iteration *j*, it is modified for the next iteration or it can be said that it is moved to a new location as shown, where *vj+1* is the velocity term derived for *j+1* iteration.

$$x^{j+1} = x^j + v^{j+1} \qquad (11)$$

A particle *x* flying in hyperspace has a velocity *v*. The best success attained by the particle is stored as *pbest* and the best among all the particles in the swarm is stored as *gbest*.

Step1: Initialize the swarm or population *Pop* randomly of desired size, let *K* in the hyperspace.

$$Pop = \{x_1, x_2, x_3, \dots x_K\}$$

Step 2: Calculate the fitness value of each particle *f(xij)*.

Step 3: Compare the fitness of each particle with its own best attained thus far as illustrated below

$$\text{if } f(x_i^j) < pbest_i : \begin{cases} pbest_i = f(x_i^j) \\ x_{i,pbest=} x_i^j \end{cases} \qquad (12)$$

else : no change in pbest and $x_{i,best}$

Step 4: Compare the fitness values of all particles and find *gbest* as shown

$$\text{if } f(x_i^j) < gbest_i : \begin{cases} gbest_i = f(x_i^j) \\ x_{i,gbest=} x_i^j \end{cases} \qquad (13)$$

else : no change in gbest and $x_{i,gbest}$

Step 5: Change the velocity of each particle for the next iteration as under, where *w* is inertia weight, *c*1, *c*2 are constants, *rand* is random variable which assumes uniformly distributed values between 0 and 1.

$$v_i^{j+1} = w * v_i^j + c_1 * rand * (x_{i,pbest} - x_i^j) + c_{2*rand*}(x_{i,gbest} - x_i^j) \qquad (14)$$

Step 6: Move each particle to a new position

$$x_i^{j+1} = x_i^j + v_i^{j+1} \qquad (15)$$

Step 7: Repeat step 2 to 6 until convergence.

Inertia weight *w*: Controls the influence of previous velocity on the new velocity. Large inertia weights cause larger exploration of search space, while smaller inertia weights focus the search on a smaller region. Typical PSO starts with a maximum inertia weight *w*max which decreases over iterations to a minimum value *w*min as shown.

$$w = w_{max} - \frac{w_{max}-w_{min}}{it_{max}} * it \qquad (16)$$

Where *it* represents the current iteration count and *it*max is the maximum iterations allowed.

Reference [15] gives the best values of *w*max and *w*min as 0.9 and 0.4 respectively for most of the problems.

B. Advantages Of PSO Compared To Conventional Methods:

1. Easy to implement and potential to achieve a high quality solution with stable convergence characteristics.

2. The particles are treated as volume less and each particle update position and velocity according to its own experience and partners experience.

3. PSO is more capable of maintaining diversity of the swarm.

4. One of reasons that PSO is attractive is that there are very few parameters to adjust [16]

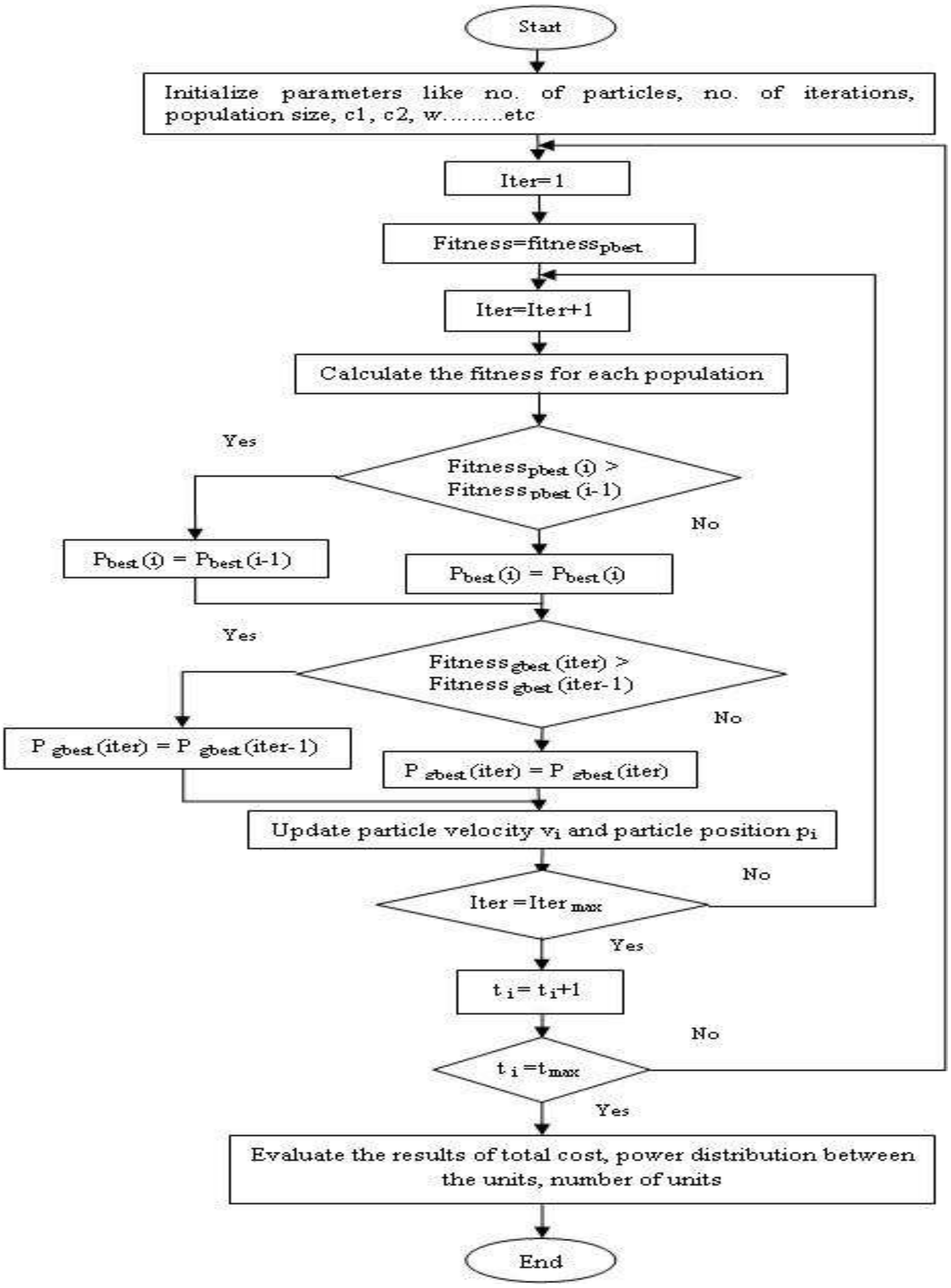

Figure 2. Flow Chart of PSO Applied To Unit Commitment

4. TEST SYSTEM AND SIMULATION RESULTS

Table 1 shows the 24 hour UC schedule for standard IEEE 14 bus test data given in Appendix B. Results given in the table are self-explanatory with hourly load demand, unit status, and power output from each committed unit. Total cost of UC schedule along with hourly production costs and total transitional cost are listed. In order to indicate the effectiveness of proposed UC algorithm, the maximum and minimum load bus voltages attained during every hour in the system are shown in the Table 2 that follows the voltages at the load buses in the system during 24 hour time period attained as high as 1.0751 PU and as low as 1.0017 PU.

Table 1. UC for IEEE 14 Bus Test System

Hour	Load		Unit Status						Power Output (MW)				Cost($)
	(MW)	1	2	3		6	8	1	2	3	6	8	X10^3
1	181.30	0	1	1		1	1	0	33.47	64.54	43.90	39.99	0.9618
2	170.94	1	0	1		1	1	60.00	0	52.70	27.19	32.14	0.9506
3	150.22	1	1	1		1	0	62.84	20.00	47.64	21.20	0	0.8415
4	103.60	1	0	0		1	1	64.49	0	0	22.23	18.00	0.6392
5	129.50	1	0	1		1	1	58.06	0	32.00	14.45	25.99	0.7710
6	155.40	1	0	1		1	0	71.19	0	54.79	30.92	0	0.8321
7	181.30	1	0	1		0	0	104.1	0	80.00	0	0	0.9551
8	202.02	1	0	1		0	0	125.7	0	80.00	0	0	1.0823
9	212.38	1	0	1		1	0	117.6	0	80.00	18.00	0	1.1479
10	227.92	1	0	1		1	0	115.1	0	80.00	36.00	0	1.2155
11	230.51	1	1	1		0	1	116.1	20.00	80.00	0	18.00	1.2824
12	217.56	1	0	1		0	1	104.1	0	80.00	0	36.00	1.1681
13	207.20	1	0	1		1	1	83.40	0	66.35	18.00	41.16	1.1271
14	196.84	1	0	1		0	0	120.4	0	80.00	0	0	1.0496
15	227.92	1	1	1		0	1	113.4	20.00	80.88	0	18.00	1.2667
16	233.10	1	1	1		0	1	89.37	37.90	72.54	0	36.00	1.2584
17	220.15	1	0	1		1	1	88.59	0	71.11	18.00	44.29	1.1944
18	230.51	1	1	1		1	1	76.95	20.00	61.76	36.00	37.70	1.2616
19	243.46	1	0	1		1	1	86.76	0	70.44	45.00	43.23	1.3026
20	253.82	1	1	1		1	1	82.58	20.00	67.30	45.00	41.11	1.3782
21	259.00	1	0	1		1	1	94.07	0	77.19	45.00	45.00	1.3857
22	233.10	1	1	1		0	1	94.16	20.00	76.45	0	45.00	1.2638
23	225.33	1	0	1		0	1	102.8	0	80.00	0	45.00	1.2067
24	212.38	1	1	1		1	0	97.98	20.00	79.35	18.00	0	1.1559
Transitional Cost													2.7198
Total Cost													29.418

Table 2. Hourly Min. and Max. Load Bus Voltages for IEEE 14 Bus Test Systems

Hour	Vmax	Vmin	Hour	Vmax	Vmin
1	1.0779	1.0358	13	1.0704	1.0275
2	1.071	1.0286	14	1.0325	0.9974
3	1.0651	1.0269	15	1.0529	1.0114
4	1.0737	1.0323	16	1.0535	1.0123
5	1.0722	1.0307	17	1.0700	1.0273
6	1.0631	1.0270	18	1.0709	1.0291
7	1.036	1.0135	19	1.0704	1.0277
8	1.0353	1.0144	20	1.0705	1.0293
9	1.0659	1.0209	21	1.0697	1.0275
10	1.0626	1.0210	22	1.0541	1.0151
11	1.0659	1.0244	23	1.053	1.0127
12	1.0546	1.0204	24	1.0582	1.0239

5. CONCLUSION

The optimal unit commitment of thermal systems resulted in enormous saving for electrical utilities. The formulation of unit commitment was discussed and the solution is obtained using the Particle Swarm Optimization method. It is found that the total operating cost obtained from the solution of unit commitment using particle swarm optimization is minimum compared to the outcomes obtained from conventional methods. And also the computation time is less.

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